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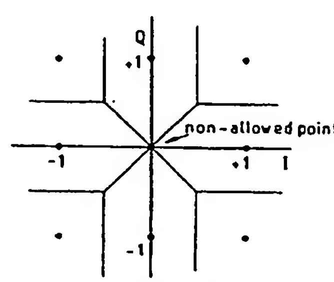
(71) Applicant: Paradyne Corporation
8550 Ulmerton Road
Largo Florida 33541(US)

(72) Inventor: Armstrong, Thomas R.
6996 122nd Drive North
Largo, Florida 33540(US)

(74) Representative: Abbott, David John et al,
Abel & Imray Northumberland House 303-306 High Holborn
London, WC1V 7LH(GB)

(54) **Double sideband quadrature carrier modulation system and method of mapping in the complex plane the point constellation of such a system.**

(57) An improved method and system are provided for the complex plane mapping of the signal structure constellation for double sideband quadrature carrier modulation. All points are mapped in an N x N constellation having 90° symmetry about the origin. All points in excess of 2^M and any point appearing at origin are omitted. Any point, in each quadrant further spaced from the origin than any other point in that quadrant are relocated. "N" and "M" are integers.



3×3 Constellation Decision Regions
FIG.1

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TITLE MODIFIED
see front page

DOUBLE SIDE BAND - QUADRATURE CARRIER MODULATION SIGNAL STRUCTURES

BACKGROUND OF THE INVENTION

The present invention relates to high-speed data transmission and in particular to signal structures for double side band quadrature carrier (DSB-QC) modulation.

In U.S. Patent 3,887,768 issued June 3, 1975 to Formey, Jr., et al for SIGNAL STRUCTURES FOR DOUBLE SIDE BAND QUADRATURE CARRIER MODULATION the inherent advantages of DSB-QC over single-sideband (SSB) and vestigial-sideband (VSB) are discussed in detail. Briefly, DSB-QC system can be designed to have a much greater insensitivity to phase jitter on the line, or to phase error in the recovered carrier than SSB or VSB signals while permitting a coherent local demodulation carrier to be derived from the received data without requiring transmission of a carrier or pilot tone.

The previously mentioned U.S. Patent 3,887,768 describes a DSB-QC modulation system in which the signal points are mapped in the complex plane on concentric rings the signal points of which are rotated by 45° from those of the next adjacent ring. While the disclosed DSB-QC constellations combat the combined effects of noise and phase jitter as discussed in the reference, in fact, improvements in the state-of-the art carrier

equipment has itself contributed substantially to the reduction of phase jitter on many communication channels so that signal constellations designed to provide the best compromise performance between noise and phase jitter are no longer optimum in the sense of overall performance, wherein the "best" performance is defined as lowest overall bit error rate.

In order to attain higher data rates in a given bandwidth, higher signal-to-noise ratios in the communications media are required. As higher signal-to-noise ratios are required, constellations for more signal-to-noise efficient signals are necessary. In the presence of noise alone, signal constellations with points equally spaced on a square grid provide a near optimum performance. Moreover, such a pattern permits simple encoding at the transmitter and simple decoding or detection at the receiver. It is known that for a given error rate and bandwidth a square grid constellation offers better signal/noise performance than a comparable concentric ring type constellation. In fact, for example, a well known ring type constellation employing 16 points for 9600 bit transmission in a Nyquist bandwidth of 2400 Hz requires 1.3 dB greater signal/noise ratio for a given symbol error rate than a comparable square grid constellation. The well known concentric ring constellation discussed above is that proposed by CCITT Recommendation V29 (offered commercially by Paradyne Corporation of Largo Florida as its MP-96 Data Modem). The square grid constellation is employed by Bell System in their model 209 Data Set.

The sacrifices paid for the greater signal to noise ratio of the square grid pattern over the concentric ring pattern are that:

1. The number of usable points must equal 2^M where M is an integer and thus M can only equal 2, 4, 8, 16, etc. As a result a grid such as 3 x 3 could not be used.

2. As the number of points increases the distance from the origin of the furthest point relative to the root mean square distance increases rapidly. Since the distance from the origin is proportional to the voltage necessary to generate the point, the peak to average voltage ratio becomes large and may lead to clipping in most communication media.

In view of the above, it is the principal object of the present invention to provide improved DSB-QC signal structures developed to provide near optimum performance in the presence of noise.

A further object is to provide such signal structures which allow simple encoding and decoding or detection.

A still further object is to provide such signal structures wherein the points in each of the four quadrants may be differentially phase encoded such that an absolute carrier reference is not necessary.

Other objects and advantages will be self-evident from the description of the preferred embodiments of the invention.

SUMMARY OF THE INVENTION

The above and other beneficial objects and advantages are attained in accordance with the present invention by providing double side band - quadrature carrier modulation signal structures wherein the constellations are composed of N x N points (N being an integer) having 90° symmetry in a modified square grid wherein for each quadrant all points which are at

the origin or further spaced from the origin than any other point are relocated or omitted. Points are omitted if the square grid is composed of more than 2^M points (M being an integer) to reduce the number of points to 2^M. Points that are relocated are brought closer to the origin and preferably to a location wherein the complexity of decoding is minimized (i.e., on an axis or on an extrapolated point on the grid).

According to another aspect of the present invention there is provided a double sideband quadrature carrier modulation system comprising input means for receiving data representable as M-bit groups in succession, means responsive to each received M-bit group to produce signals respectively representing the co-ordinate values of a point selected in response to the M-bit group from among 2^M points disposed with 90^o symmetry about the origin in a square array of N x N, omitting any point appearing at the origin and any points in excess of 2^M, and in which array the point in each quadrant which is furthest from the origin is relocated, and modulating means responsive to said signals to modulate corresponding quadrature phases of a carrier.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIGURE 1 depicts a 3 x 3 constellation which contains eight possible points;

FIGURE 2 depicts a 6 x 6 constellation which contains thirty-two possible points;

FIGURE 3 depicts a possible encoding scheme for a 6 x 6 constellation;

FIGURE 4 illustrates differential gray coding of the quadrants to eliminate the need for a carrier phase reference;

FIGURE 5 depicts prior art related to a 8 x 8 constellation;

FIGURE 6 depicts a modified 8 x 8 constellation;

FIGURE 7 depicts another modified 8 x 8 constellation; and

FIGURE 8 is a block diagram of one example of a system embodying the present invention;

DESCRIPTION OF PREFERRED EMBODIMENTS

Data rates heretofore employed for digital signalling over telephone channels may be expressed as 2400 x 2^M where M is an integer. The standard rates attained therefore are 2400, 4800 and 9600 bits per second where M = 0, 1, and 2 respectively. To conveniently attain these rates, modems which are switchable and therefore provide all rates usually signal at a symbol rate of 2400 symbols per second. Transmission at 2400 bps requires one bit to be encoded into one of two possible phases each symbol time. 4800 bps requires two bits to be encoded into one of four possible phases each symbol time and 9600 bps requires four bits to be encoded into sixteen points. The means for encoding and a method for implementing the encoding scheme are set forth in the previously mentioned U.S. Patent 3,887,768.

In a modem providing 2400, 4800 and 9600 bps operation it is desirable to provide also the rate of 7200 bps particularly since certain terminals are designed to operate at 7200 bps. To obtain this rate, it is necessary to obtain 3 bits per symbol or eight possible points. In accordance with the present invention, the signal constellation of Figure 1 provides this function as it allows three bits to be encoded into eight possible points. To obtain eight points on a

square constellation, the dimensions of the square must be at least 3 x 3 since anything less would not provide sufficient points. The set of points may be represented by the co-ordinates +1, 0, -1 on the in-phase and quadrature axes. In accordance with the present invention the zero point is eliminated thereby leaving the required eight points. Not allowing the zero point to occur has advantage of permitting continuous tracking of the carrier phase since reception of the 0,0 point does not convey carrier phase information. Since the 0,0 point has been eliminated no determination need be made as to whether or not the furthest point from 0,0 in each quadrant is further than all other points and no point relocating need be done.

The eight possible phases shown in Figure 1 are differentially encoded such that an absolute carrier phase is not required.

Figure 2 illustrates one quadrant of a 6 x 6 constellation which can be used to yield a data rate of 12,000 bits per second for a symbol rate of 2400 symbols per second. In this case each symbol is represented by 5 bits hence $2^M = 2^5 = 32$ and thus N x N must exceed 32. The lowest value for N is hence 6. Accordingly, 6 levels are allowed on each axis, but only 32 possibilities are permitted since for each symbol time five bits are encoded into a point. There are thus for non-allowed points which would occur at co-ordinates (-5,-5), (-5,5), (5,-5) and (5,5). Omitting these points minimizes the peak to average power level of the transmitted signal.

Figure 3 illustrates one candidate coding scheme for the constellation of Figure 2 wherein the first two bits denoted by XX are differntially encoded between quadrants such that a carrier phase reference is not necessary. Differential coding of the first two bits between quadrants of the scheme of Figure 3 to eliminate the requirement for a carrier phase reference is shown in Figure 4.

To achieve a data rate of 14,400 bps at a symbol rate of 2400 symbols per second requires 6 bits to be encoded into one of sixty-four possible points each symbol time. This may be accomplished in accordance with the scheme of Figure 5 which illustrates the prior art wherein all sixty-four points are spaced equally with respect to the in-phase and quadrature axes. However, the points located at co-ordinates (-7,-7), (-7,7), (7,-7) and (7,7) cause a relatively high peak to average power ratio because of their maximal distance from point 0,0 (i.e., at the extreme points the power requirement is $24.5A^2$. Two modifications to the constellation of Figure 5 in accordance with the present invention which yield a lower peak to average power ratio yet which preserve equal spacing on each axis and which provide symmetry in all four quadrants are illustrated in Figures 6 and 7. This is accomplished in each case by relocating the point in each quadrant further spaced from the origin than any other point (i.e., 7,7; -7,7; 7,-7 and -7,-7) to positions closer than the origin.

In Figure 6, the point at (7,7) is relocated to (9,1). Similarly, the point at (-7,7) is relocated to (-1,9). (-7,-7) is relocated to (-9,-1) and (7,-7) is relocated to (1,-9).

In Figure 7, the point at (7,7) is relocated to (9,0). Similarly, the point at (-7,7) is relocated to (0,9). (-7,-7) is relocated to (-9,0) and (7,-7) is relocated to (0,-9).

In each case the danger of the signal being clipped is significantly reduced since the peak power requirement is reduced by 0.8 dB as indicated in Figures 6 and 7.

Figure 8 shows in block diagrammatic form one example of apparatus for encoding serial binary data in double sideband quadrature carrier modulation form according to the invention. The input data is received via a line 1 by an M-bit shifting register 2. Every M clock cycles the

M-bit number stored in the register 2 is transferred to a buffer store 3 under control of signals derived from a clock oscillator 4 by a divide-by-M circuit 5. The M-bit number in the store 3 is used as an address input for a read-only-memory 6 which stores the co-ordinates of the point of the constellation corresponding to the number stored in the store 3 and produces these on output conductors 7 and 8 respectively. The data output from the ROM 6 on the conductors 7 and 8 is converted to analogue form by converters 9 and 10 respectively at instants determined by the outputs of the divide-by-M circuit 5. After passing through low pass filters 11 and 12 respectively the analogue signals from the converters 9 and 10 are applied to respective modulators 13 and 14 to which in phase and quadrature carrier oscillations are applied directly from a carrier oscillator 15 and via a quadrature wave phase shifting circuit 16. The outputs of the modulators 13 and 14 are combined in a circuit 17 to produce the required output signal on a conductor 18.

The operation of the circuit of Figure 8 is quite straightforward and can readily be understood from consideration of the foregoing description and the disclosure in the previously mentioned United States Patent Specification No. 3 887 768.

The encoded signal can be decoded by a circuit similar to that shown in Figure 8 to reproduce the transmitted data in suitable form. It will be appreciated that the system described is only one example of possible systems embodying the present invention and many modifications could be made to the described circuit which will be apparent to one skilled in the art.

Claims:

1. A method of mapping in the complex plane the point constellation of a double sideband - quadrature carrier modulation system wherein each symbol conveys M bits of information comprising the steps of:

(a) mapping the points in a constellation composed of N x N points (N being an integer) having 90° symmetry about the origin;

(b) omitting any point appearing at the origin;

(c) omitting any points in excess of 2^M (M being an integer); and

(d) relocating any point in each quadrant further spaced from the origin than any other point.

2. A method in accordance with claim 1 wherein M = 3, N = 3, the points are arranged along -1, 0 and +1 along each axis and the origin point (0,0) is omitted.

3. A method in accordance with claim 1 wherein M = 5, N = 6, the points are arranged on -5, -3, -1, 1, 3 and 5 along each axis, and the points at 5,5; -5,5; 5,-5; and -5,-5 are omitted.

4. A method in accordance with claim 1 wherein M = 6, N = 8; the points are arranged at -7, -5, -3, -1, 1, 3, 5 and 7 along each axis, and the points located at (7,7), (-7,7), (7,-7) and (-7,-7) are relocated to (9,1), (-1,9), (1,-9) and (-9,-1) respectively.

5. A method in accordance with claim 1 wherein M = 6, N = 8, the points are arranged at -7, -5, -3, -1, 1, 3, 5 and 7 along each axis and the points located at (7,7), (-7,7), (7,-7) and (-7,-7) are relocated to (9,0), (0,9), (0,-9) and (-9,0) respectively.

6. A double sideband quadrature carrier modulation system comprising:

input means for receiving data representable as M-bit groups in succession,

means responsive to each received M-bit group to produce signals respectively representing the co-ordinate values of a point selected in response to the M-bit group from among 2^M points disposed with 90^o symmetry about the origin in a square array of N x N, omitting any point appearring at the origin and any points in excess of 2^M, and in which array the point in each quadrant which is furthest from the origin is relocated, and

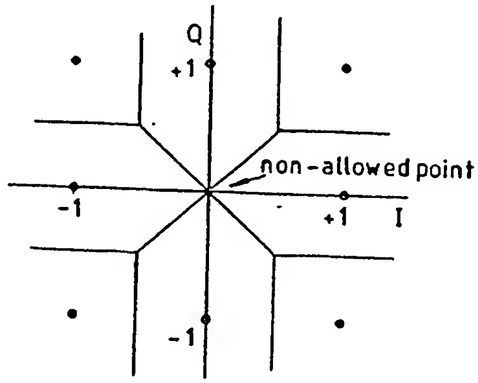
modulating means responsive to said signals to modulate corresponding quadrature phases of a carrier.

7. A system according to claim 6 wherein M = 3, N = 3, the points are arranged along -1, 0 and +1 along each axis and the origin point (0,0) is omitted.

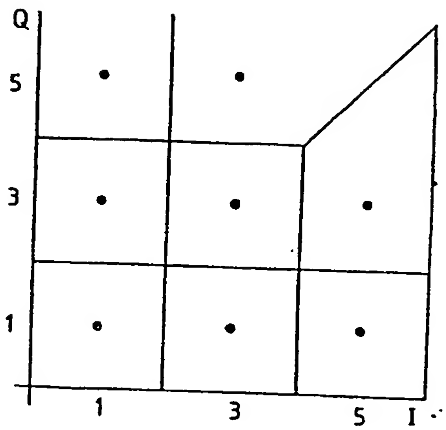
8. A system according to claim 6 wherein M = 5, N = 6, the points are arranged on -5, -3, -1, 1, 3 and 5 along each axis, and the points at 5,5; -5,5; 5,-5; and -5,-5 are omitted.

9. A system according to claim 6 wherein M = 6, N = 8, the points are arranged at -7, -5, -3, -1, 1, 3, 5 and 7 along each axis, and the points located at (7,7), (-7,7), (7,-7) and (-7,-7) are relocated to (9,1), (-1,9), (1,-9) and (-9,-1) respectively.

10. A system according to claim 6 wherein M = 6, N = 8, the points are arranged at -7, -5, -3, -1, 1, 3, 5 and 7 along each axis and the points located at (7,7), (-7,7), (7,-7) and (-7,-7) are relocated to (9,0), (0,9), (0,-9) and (-9,0) respectively.

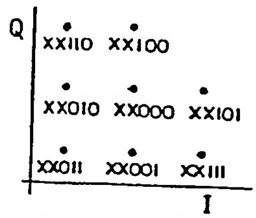


3×3 Constellation Decision Regions
FIG.1

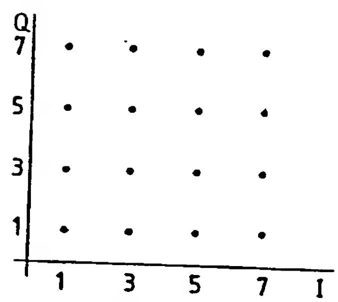


6×6 Constellation QAM Decision Regions (Quadrant 1 only shown)

FIG.2



12000 bps-Modified 6×6
FIG.3



14400 bps 8×8 Constellation (Quadrant 1 only shown)
FIG.5 Prior Art

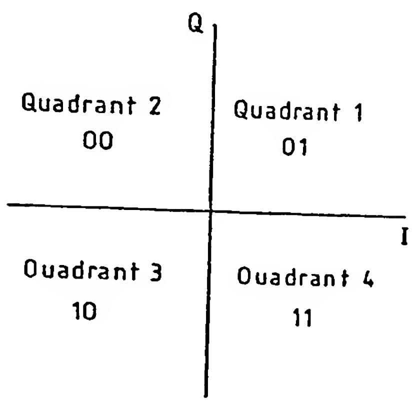
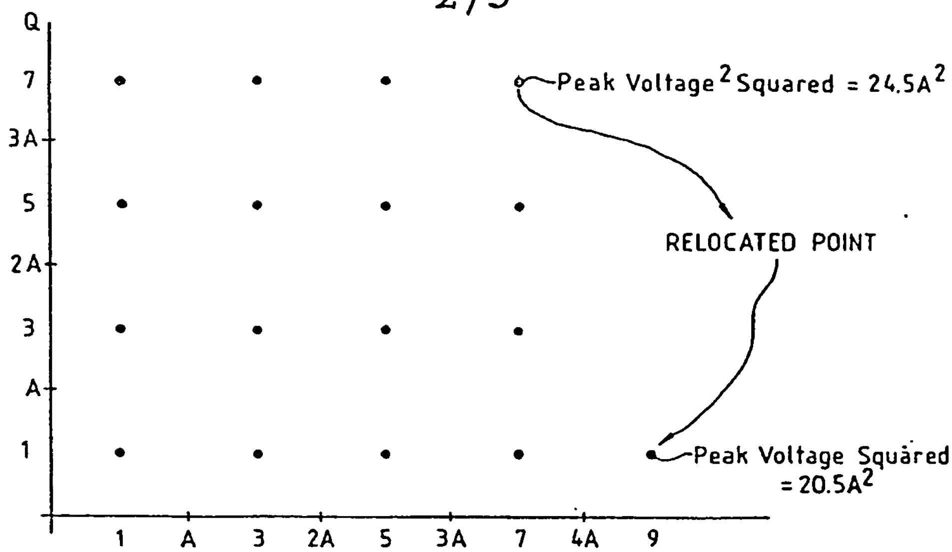
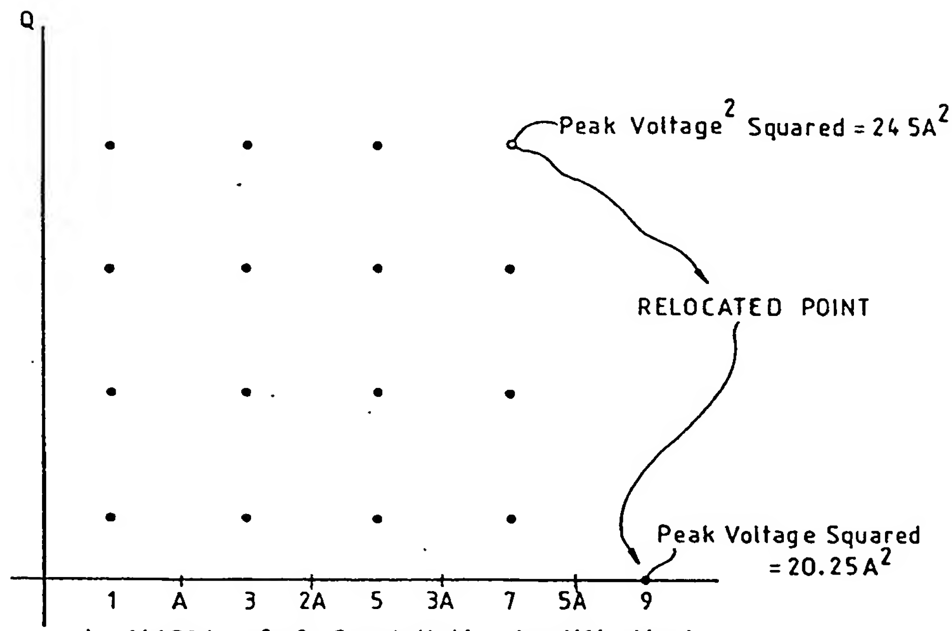


FIG.4



14400 bps. 8 × 8 Constellation (modification 1)

FIG. 6



14400 bps. 8 × 8 Constellation (modification)

FIG. 7

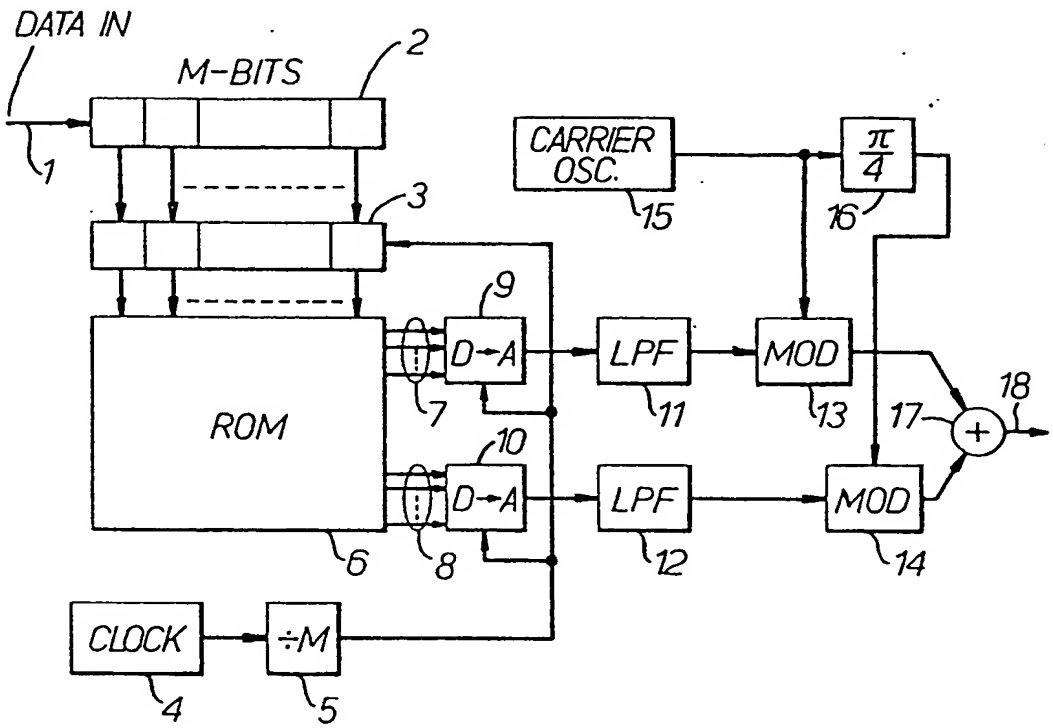

DATA IN
M-BITS
2
1
3
CARRIER OSC.
15
π/4
16
9
D→A
LPF
MOD
ROM
7
11
13
17
18
+
10
D→A
LPF
MOD
6
8
12
14
CLOCK
÷M
4
5

FIG. 8.

0031193
Application number
EP 80302927.1

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EUROPEAN SEARCH REPORT

Category	DOCUMENTS CONSIDERED TO BE RELEVANT Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
	GB - A - 1 356 179 (KOKUSAI DENSHIN) + Page 2, lines 13-111; page 3, lines 88-129; fig. 1-7, 12, 13 +	1,6	H 04 L 27/18 H 03 C 3/00
D	US - A - 3 887 768 (FORNEY) + Column 1, line 1 - column 6, line 2; fig. 1-4b, 6 +	1,6	
	GB - A - 1 530 417 (CSELT) + Page 1, line 60 - page 4, line 36; fig. 1-5 +	1,6	TECHNICAL FIELDS SEARCHED (Int.Cl. 3)
	US - A - 3 988 539 (MOTLEY) + Column 4, line 1 - column 8, line 51; fig. 1-6 +	1,6	H 04 L 27/00 H 03 C 3/00 H 03 D 3/00 H 03 K 7/00 H 03 K 9/00
	GB - A - 1 516 040 (INTERNATIONAL BUSINESS MACHINES) + Page 1, line 22 - page 2, line 47 +	1	

CATEGORY OF CITED DOCUMENTS

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E: conflicting application
D: document cited in the application
L: citation for other reasons

&: member of the same patent family, corresponding document

X The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	04-12-1980	HAJOS